

FULL-SCALE HF ANTENNA PATTERN MEASUREMENTS  
MADE WITH TRANSMITTER TOWED BY AIRCRAFT

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UNITED STATES ARMY ELECTRONICS RESEARCH AND DEVELOPMENT LABORATORY  
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SRI Project 3670

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A handwritten signature in cursive script, reading "Cecil Barnes", is written over a horizontal line.

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Communication Laboratory

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## ABSTRACT

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A practical method of making full-scale pattern measurements of HF antennas in the field has been developed and successfully used. An airplane tows a small transmitter operating on four frequencies around the antenna to be measured; it is thus possible to record four antenna patterns simultaneously.

The battery-operated transmitter and antenna assembly is small enough to constitute an elementary dipole; provision is made for causing the radiated signals to be either vertically or horizontally polarized.

## I INTRODUCTION

The radiation pattern of a large antenna over an irregular ground plane of uncertain conductivity is generally difficult or impossible to calculate; the unknown ground losses also complicate the use of modeling techniques. It therefore becomes necessary to make full-scale measurements in the field.

If it is necessary to know the radiation pattern for angles above the horizon, the use of an airplane or helicopter is indicated. Of the various flight paths that can be visualized, those convenient to use in practice are: vertical descents, straight overhead runs, straight "fly-by" runs that do not go overhead, and circular paths around a fixed ground point.

This memorandum deals with a method of making flight tests using the latter plan, an airplane flying around the unknown ground antenna on a circular path while transmitting a constant signal. Receiving equipment on the ground records the voltage induced at the antenna terminals as a function of azimuth angle; from this information the antenna pattern (which is the same for either transmitting or receiving) can be plotted.

## II DISCUSSION

For this method to be successful, it is essential that the signal from the aircraft be of constant amplitude and known polarity; indeed, for a complete solution of the problem, it should be possible to transmit from the airplane a signal whose polarity could be set to any one of three mutually perpendicular axes. However, transmitting from an airplane in this manner is not feasible for frequencies in the HF band (3 to 30 Mc) because a limitation occurs when the test frequency approaches the resonant frequency of the airframe. Oscillations set up in the wings, vertical stabilizer, or fuselage will cause additional radiation, thus altering the pattern and the dipole axis.

In order to avoid this, the antenna and a battery-operated transmitter may be placed in a streamlined housing and towed some distance behind the airplane by a nonconducting rope; the distance separating the battery-operated transmitter from the airplane must be sufficient so that reradiation from the latter is a negligible factor. In practice, this distance is about 200 feet. If the whole transmitting assembly is made much smaller than the smallest wavelength to be used, the radiation pattern will be that of an elementary dipole in free space. The orientation of this dipole will depend on the configuration of the assembly; it could be made vertical, tangential to the circular flight path, or radial to the flight path, as desired.

Figure 1 shows a small battery-operated transmitter which has been made and successfully used in pattern measuring work. The device, known as a Xeledop (transmitting elementary dipole with optional polarization), can be set for either vertical or fore-and-aft horizontal polarization.\*

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\* The third direction of polarization, which is not a contributing factor of any great importance in making circular flights at low elevation angles, would be horizontal and at right angles to the line of flight. The present Xeledop model cannot achieve this polarization.



FIG. 1 XELEDOP WITH COVER REMOVED

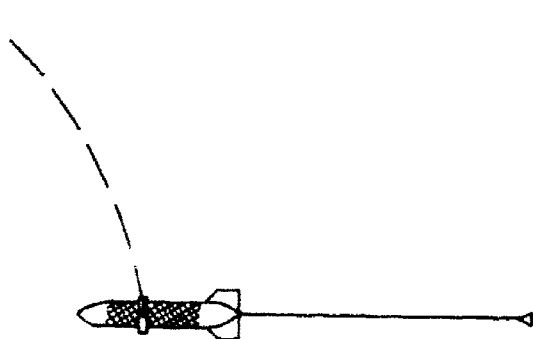


Figure 2(a) shows the configuration of the Xeledop used in these tests when it is set for horizontal polarization. In this case, the wire trails out in the slip stream to an essentially horizontal position. Figure 2(b) shows the configuration of the Xeledop when set for vertical polarization. The top half of the dipole consists of a wire attached to the last 10 feet of the tow rope. For this part of the tow rope to be as nearly vertical as possible, the Xeledop should be heavy and streamlined, and the wire and rope together should be as thin as possible so as to present minimum drag. A similar line of reasoning applies to the antenna weight and to the wire supporting it, which together form the bottom half of the dipole. It can be seen from Figure 2(b) that the dipole is actually tilted forward to some extent. Tests made by flying over a horizontal dipole mounted on the ground revealed that this forward tilt angle was about 18 to 19 degrees. This is considered relatively insignificant, but we hope to reduce it on later flights by allowing part of the top half of the dipole antenna wire to trail back from the tow rope. The metal frame of the Xeledop is electrically connected to the bottom antenna wire.

The Xeledop transmits sequentially on four crystal-controlled frequencies, which in one instance were 5.1, 9.1, 15.1, and 29.0 Mc. The transmitted signal consists of approximately four pulses per second, each successive pulse being on a different frequency and lasting  $1/5$  second. This signal is received on the ground by four receivers connected to the unknown antenna through a multicoupler. The receiver outputs are recorded on a multichannel recorder, as indicated in Figure 3.

At the same time, an operator with an optical device tracks the aircraft from a location near the unknown antenna. Azimuth and elevation angles are automatically transmitted to the recorder, which thus records on a paper-strip chart four relative field-strength measurements and their associated bearing angles.

In order to calibrate the equipment, a signal generator is provided which can be substituted for the unknown antenna. By means of this generator, a "taircase" calibration is recorded on each channel of the

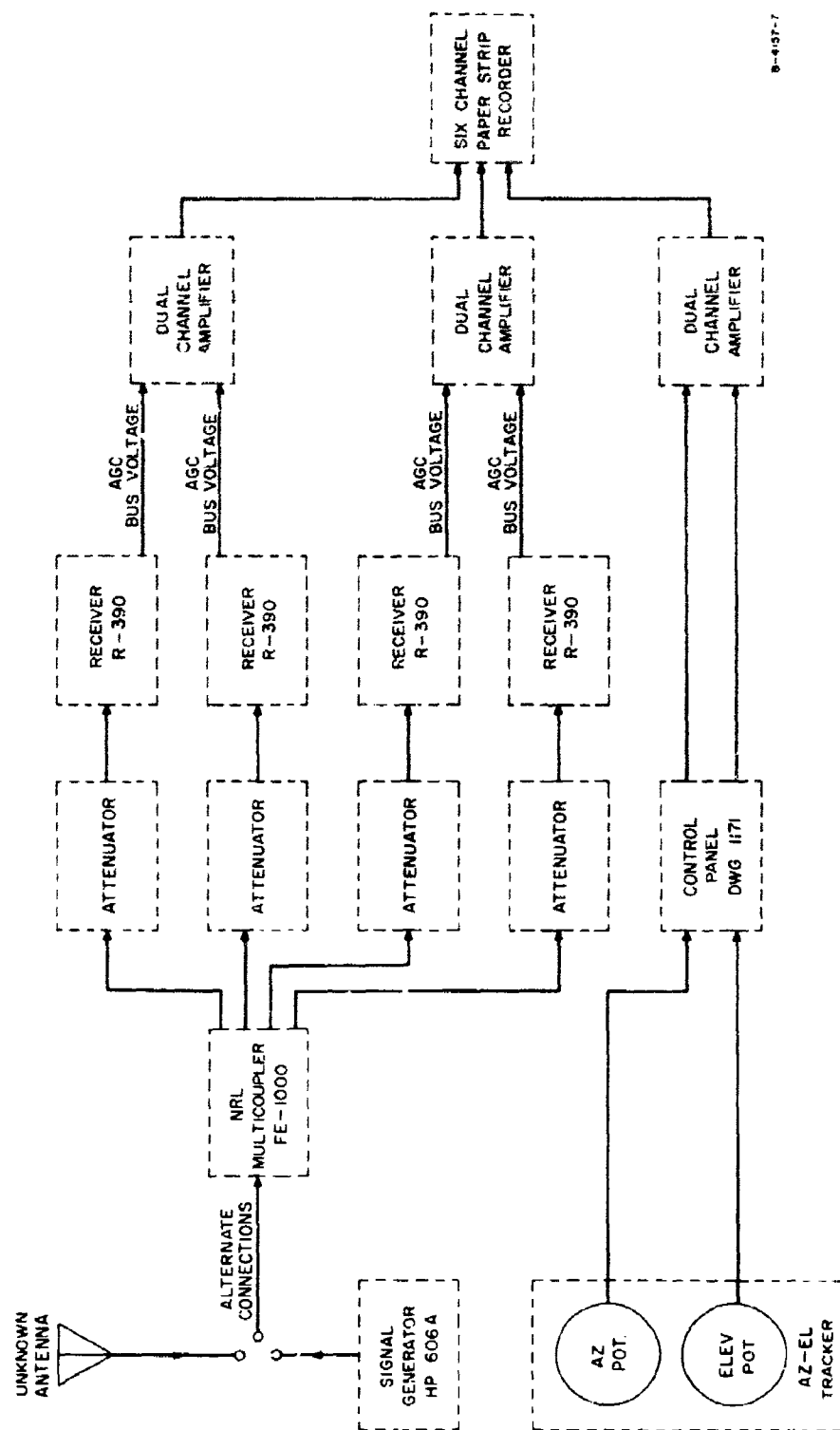


(a)  
HORIZONTAL POLARIZATION



(b)  
VERTICAL POLARIZATION

FIG. 2 XELEDOP ANTENNA CONFIGURATIONS



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FIG. 3 RECEIVING AND RECORDING EQUIPMENT

chart either before or after each flight test. The individual attenuators shown in each channel of Figure 3 are so adjusted prior to calibration that the signal at the receiver antenna terminals does not exceed 300  $\mu$ v during one orbit of the aircraft. The recorder operates from the AGC bus voltages in the receivers with the result that a decibel scale on the record appears to be nearly linear. However, linearity is not assumed in reducing the data; reference is always made to the staircase calibration.

The power radiated from the present Xeledop model is not the same for each frequency, nor is the same power radiated on vertical and horizontal polarizations. This difference is caused by varying losses in the antenna matching networks due to different antenna impedances associated with the different configurations. Therefore, in general, it is not possible at present to compare the gains of an unknown ground antenna at two different frequencies unless some method of cross correlating the Xeledop signals is used. The same also applies to comparisons between vertically and horizontally polarized signals.

When a measurement is made on a vertically polarized antenna, the gain relative to a monopole can be found by direct comparison. A quarter-wave monopole is erected over a ground screen of radial wires and used to receive signals from the Xeledop. If the flights around the unknown antenna and the monopole occur within a short time (say one-half hour) of each other, it can be assumed that the Xeledop power output has not changed and thus that a direct comparison has been obtained at one frequency. To obtain data at more than one frequency, it is necessary either to construct separate quarter-wave monopoles or to estimate the effect of using a monopole at the wrong frequency. This estimate (which is based on the mismatch loss caused by the difference between the antenna impedance and the 50-ohm transmission line impedance) may not be very accurate, but the method has the distinct advantage of simplicity as compared to erecting a number of large quarter-wave monopoles.

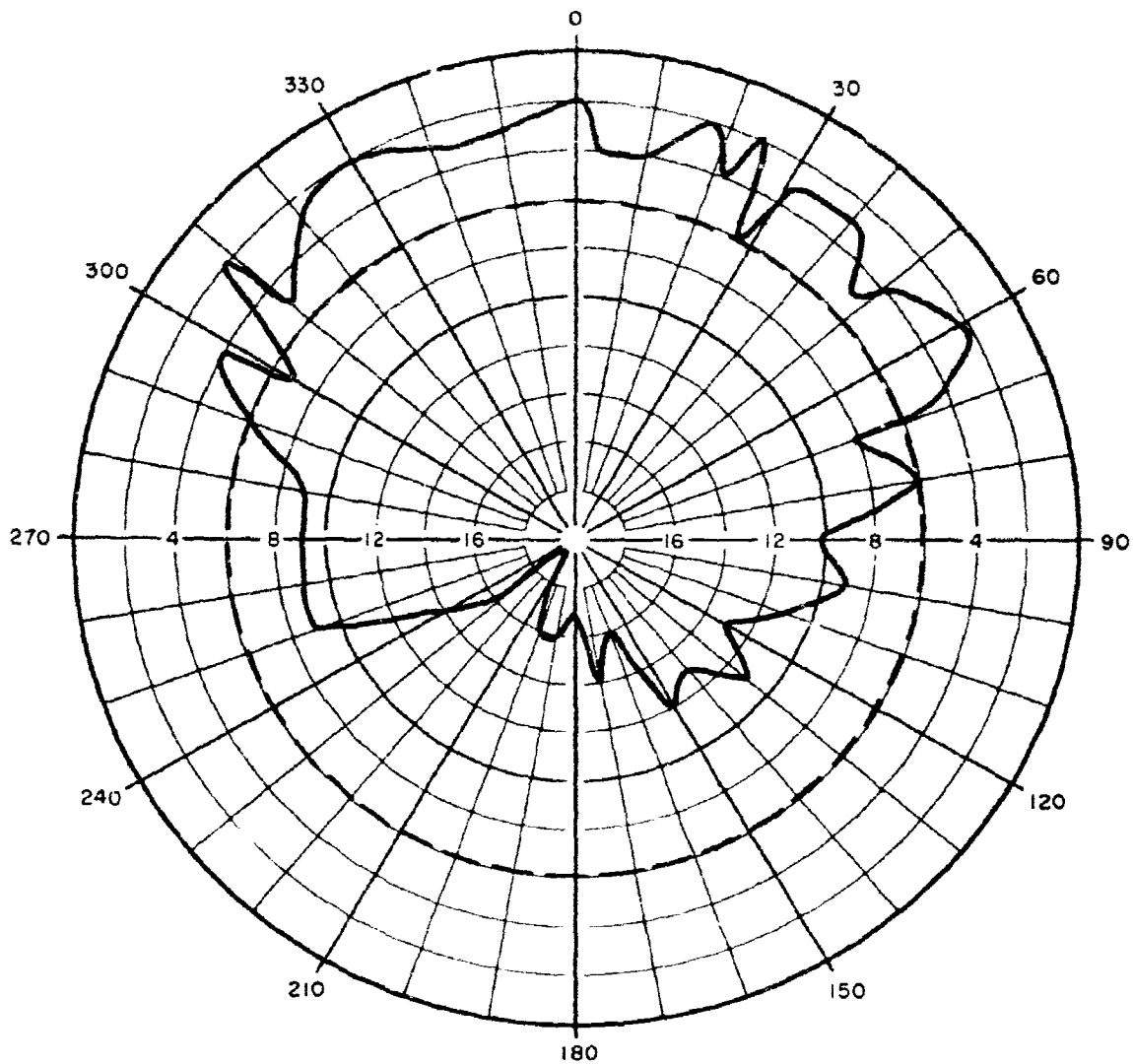
An example of one case where a comparison was made between a vertically polarized log-periodic antenna and a quarter-wave monopole

tuned to zero reactance is presented in Fig. 4. This shows that at an elevation angle of 24 degrees above the horizon and at 15.1 Mc this particular antenna had a gain of 4 db over a monopole in the forward direction.

Figure 5(a) shows an over-all view of the flight plan used in making the measurements described. In order to simplify the navigation problem for the pilot, he is instructed to fly over the same ground track each time, regardless of altitude, as indicated in Fig. 5(b). The slant-line distance to the airplane thus increases as the airplane goes higher, which necessitates a correction of the recorded data. When the Xeledop is horizontally polarized, as indicated in Fig. 6(a), it radiates signals of equal strength toward the unknown ground antenna at all altitudes. The field strength at the ground antenna, being inversely proportional to the distance, is therefore proportional to the cosine of the elevation angle,  $\theta$ . When the Xeledop is vertically polarized, it is necessary to apply corrections for increasing slant-line distance and dipole pattern combined. The dipole pattern is also a cosine function, and in this case the field strength on the ground is proportional to  $\cos^2\theta$ , as shown in Fig. 6(b).

One radius that is commonly used for these flights is 2-1/2 miles. At the speed the aircraft flies and with the cross winds encountered, it is sometimes necessary to bank 3-1/2 degrees to stay on this track. The fact that the Xeledop is also banking is ignored when making corrections for the dipole pattern because the effect would be minor.

The pilot is provided with aerial photographs or maps on which the prescribed track has been drawn, and he attempts to follow this track as closely as possible while maintaining a constant altitude for one orbit. The problem of maintaining a constant radius becomes more difficult at high altitudes, but here the ground personnel can assist the pilot by advising him of variations appearing in the recorded elevation angle. Since a constant altitude can be maintained easily, a variation of elevation angle indicates a change of radius. As an example of how far the airplane can safely deviate from the correct track, it should be



— VERTICALLY POLARIZED LOG PERIODIC ANTENNA  
 - - - QUARTER-WAVE MONOPOLE  
 FREQUENCY: 15.1 Mc  
 DECIBEL SCALE

ELEVATION ANGLE: 24°

FIG. 4 LOG-PERIODIC ANTENNA GAIN RELATIVE TO A MONOPOLE AT 15.1 Mc

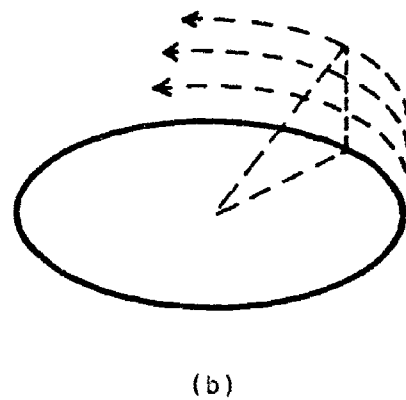
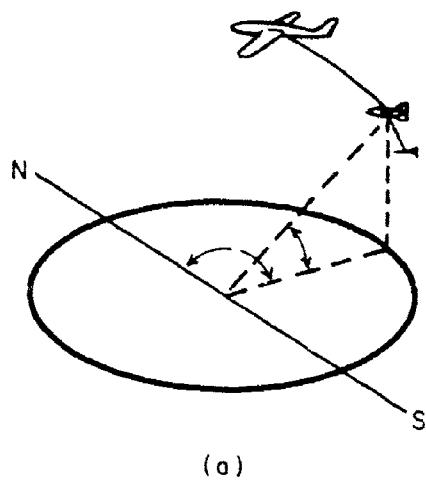


FIG. 5 CIRCULAR FLIGHT PATHS

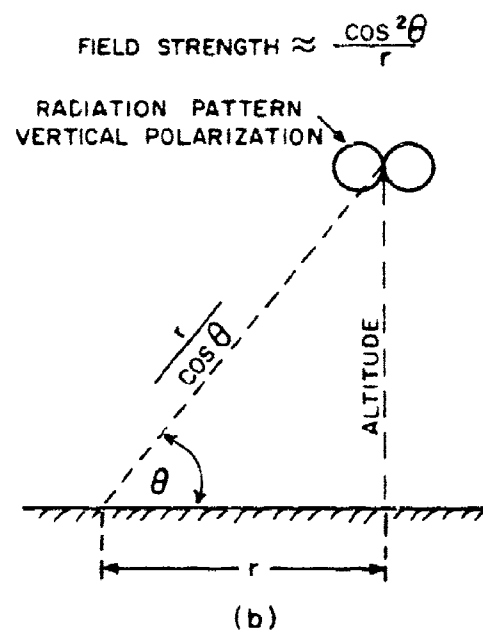
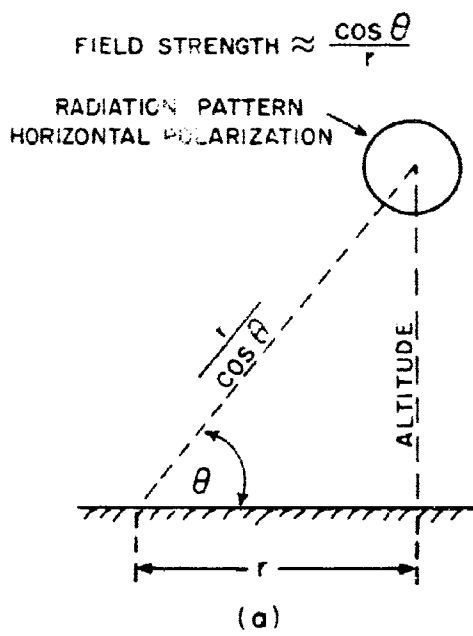


FIG. 6 FIELD STRENGTH vs. ELEVATION ANGLE AT GROUND ANTENNA



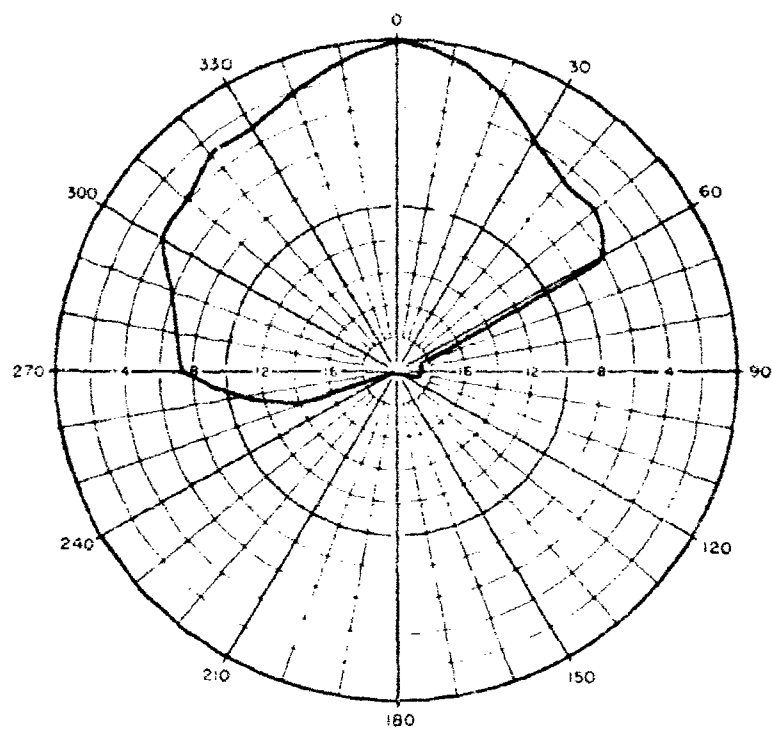
noted that errors of  $\pm 0.2$  mile on each side of 2.5 miles would cause changes in the field strength at the ground antenna of approximately  $\pm 1$  db, with the airplane at a low angle of elevation. At higher elevation angles, greater deviations can be tolerated, because the rate of change of the slant-line distance is less than the rate of change of the radius of the flight path. It is believed that the accuracy achieved in the final plot of the pattern lies within  $\pm 2$  db. In reducing the data, the greatest attention is given to that part of the pattern lying within  $\pm 70$  degrees of the forward or main-beam direction; here the detail is traced out with some care. Around the back part of the pattern, only the data from the major lobes and nulls are computed. In all cases, fractions of a decibel are ignored; values are taken to the nearest db.

The optical tracking device used for following the aircraft consists of an elbow telescope so mounted as to turn potentiometers as the telescope moves in azimuth and elevation. It is estimated that this arrangement results in an over-all accuracy of  $\pm 5$  degrees for azimuth and  $\pm 3$  degrees for elevation in the final plots of antenna patterns.

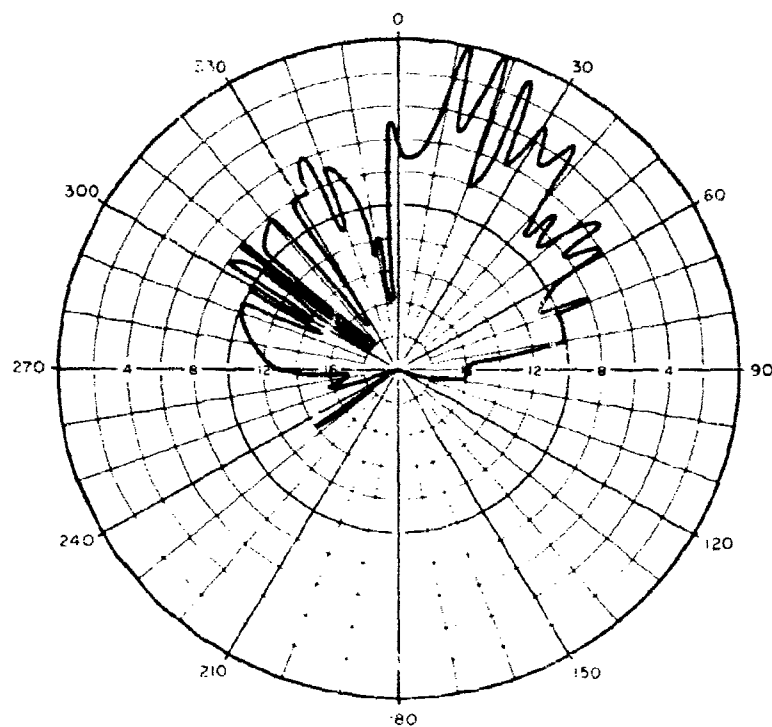
In many cases where the airplane repeats a run, good correlation is obtained between one run and the next; the fine-lobe structure is repeated exactly the second time around, although the whole pattern may be offset a few degrees due to an error in reading the azimuth angle. On occasions when good correlation is not obtained, it is usually possible to establish that the airplane did not follow the same track on each revolution. A very small change in flight path can make a marked difference in the depths or locations of sharp nulls.

In presenting plots of the radiation patterns, it has seemed significant to show the scalloped edges as they were recorded, with the understanding that these represent typical cases rather than exact portrayals of the fine-lobe structure to be found at specified elevation angles.

The Xeledop has been used to measure the radiation patterns of a vertically polarized log-periodic antenna, an equiangular spiral antenna (which is circularly polarized), and a rhombic antenna, which is predominantly horizontally polarized. An example of the results obtained when measuring antenna patterns using crossed polarization is shown in Fig. 7. The antenna that was measured was vertically polarized, and Fig. 7(a) shows the pattern when the Xeledop was also vertically polarized. Figure 7(b) shows the pattern (not to the same scale) when the Xeledop was horizontally polarized.



(a) XELEDON VERTICALLY POLARIZED



(b) XELEDON HORIZONTALLY POLARIZED

FREQUENCY 15.1Mc

ELEVATION ANGLE 12°

FIG. 7 LOG-PERIODIC ANTENNA PATTERNS WITH STRAIGHT AND CROSSED POLARIZATION

### III FUTURE WORK

Addenda to this research memorandum will be issued concerning antennas measured by the method described here. Meanwhile, work is progressing on a new Xeledop that can be changed from vertical to horizontal polarization without retuning and therefore without change of radiated power. This will allow direct comparison to be made between antennas of different polarizations.

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